Cancellation of Zigbee interference in OFDM based WLAN for multipath channel

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Abstract— **Zigbee is one of the major sources of interference in 2.4GHz band for WLANs. It is seen whenever any Zigbee system is operating near to the WLAN system and transmitting signal at same frequency, time as of WLAN's, the later ones performance detoriate severely. So in this paper an algorithm is proposed to estimate Zigbee interference component present in all OFDM based WLANs sub-carriers and cancel out the Zigbee interference from the received signal of WLANs receiver for multipath fading channels in frequency domain. Simulation results shows for high SNR values full cancellation of Zigbee interference or zero BER is possible**.

Index Terms— **WLAN, Zigbee, OFDM, OQPSK, narrowband**

I. Introduction

Recent development in wireless technology shows that next generation wireless system will provide users with variety of wireless services assuming coexistence of different wireless technology at the same time and same place. At present IEEE802.11g standard based WLAN which is intended for wireless network, is one of the most popular device adopted in home, office, institution etc. It can operate within range of 100 meter distance in 2.4GHz ISM band.

Zigbee is another wireless technology intended for personal area network. It transmit within a range of 10meters in same 2.4 GHz unlicensed ISM band. As both the system operates in same ISM band (i.e 2.405-2.480GHz) whenever they operate at the same time results in collision.

From the literature search some techniques, to mitigate narrowband interference by estimating interference component with OFDM null carriers using pseudo inverse of narrowband signal's transfer function [3] or erasing the sub carriers[1] can be found. But all this techniques having there own limitation. In this paper an algorithm is proposed to cancel Zigbee interference in OFDM based WLANs. In the proposed cancellation algorithm interference component in all the sub carriers are estimated and cancelled. It is assumed that WLAN is monitoring the channel before transmission using spectrogram [2]. From this it can detect any Zigbee signal interference.

The paper is organized as follows: In section 2 Overview of OFDM system and Zigbee interference modeling is given. In section 3 Cancellation algorithm, estimation of frequency, power of Zigbee and channel tap value is given In section 4 simulation results are given Section 5 conclude the paper summarizing of the simulation results.

II. Overview of the WLAN and Zigbee

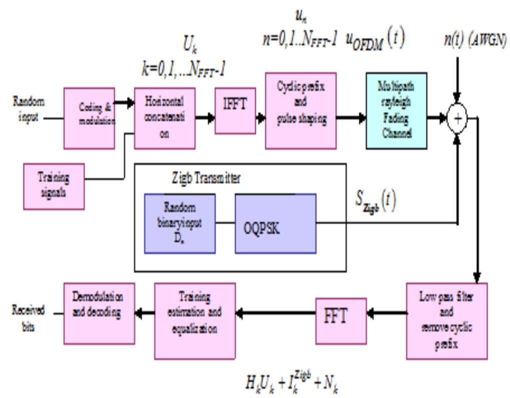

Figure 1: Zigbee interference in OFDM based WLAN

IEEE802.11g[7] standard based WLAN uses OFDM modulation technique. In OFDM modulation multiple low data rate carriers are combined by transmitter to form a composite high data rate transmission. IEEE802.11g supports different data like 6, 9, 18, 36, 48,54Mbps. Use of cyclic prefix makes OFDM signal immune to multipath effect, inter carrier interference (ICI), intersymbol interference (ISI) etc.

Zigbee[5] system is designed for mainly low cost, low power applications. In the 2.4GHz range bit rate of Zigbee is 250kbs/s. Zigbee uses direct sequence spread spectrum (DSSS) to make the signal robust against interference. Zigbee system has 16 different 32-chip sequences. So to make the signal DSSS 4bit information sequence is mapped into any of the 32 chip sequence which results in 2Mchip/s chip rate. Then chips are modulated by Offset-QPSK**.**

III. Interference Model and Cancellation

In this section first a mathematical model of Zigbee interference is given, and then an algorithm is proposed to estimate and cancel Zigbee interference from OFDM based WLAN receiver.

The received signal in the OFDM receiver for the k^{th} subcarrier is given by[9] [5][6] :

$$R_k = H_k U_k + I_k + N_k \qquad (1)$$

Where U_k is the complex MQAM signal and H_k denotes the k^{th} channel component corresponds to equivalent channel transform matrix and I_k is the interference

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component corresssponds to k^{th} sub-carrier of OFDM system and N_k is the AWGN.

The idea is to model interference I_k^{Zigb} as function of transmitted unknown binary data to model the interference as given below:

$$I_k = \sum_{n=0}^{p-1} a_{n,k} D_n + C_k \tag{2}$$

The value of p depends on the number of unknown transmitted binary data of Zigbee system transmitted within one symbol duration of the OFDM system. The values of $a_{n,k}$, C_k can be found from the fixed parameters of both system like modulation type, pulse shape used in the Zigbee system , tap values of the receiver low pass filter, cyclic prefix remove matrix, FFT matrix in OFDM receiver.

A. Interference Model of Zigbee signal in OFDM receiver

This subsection show how to model the Zigbee interference for each of the OFDM subcarrier as a function of unknown binary data transmitted within a symbol duration of OFDM signal.

The OQPSK modulated signal can be written as[5]:

$$\begin{aligned} s_z(t) &= \sqrt{P} D_0 p(t) \cos 2\pi f_h t \\ &+ \sqrt{P} D_1 p(t - T_Z) \sin 2\pi f_h t \end{aligned} \tag{3}$$

Where $D_0, D_1 \in \{+1, -1\}$ denotes binary data for in phase , quadrature phase component of OQPSK signal and $p(t)$ is the shaping pulse which is given by[5]:

$$p(t) = cos\left(\frac{\pi t}{2T_Z}\right) \qquad 0 \le t \le 2T_Z \tag{4}$$
$$= 0 \qquad \text{elsewhere}$$

And f_h is the centre frequency among any of the 16 channels of the Zigbee and P is the signal power. Let there are N samples for the T_Z symbol duration, then the equation(3) can be written in matrix form as given:

$$\mathbf{S}_{Z_{n,l}} = \sqrt{P} \begin{bmatrix} P_l(n2T_z) & Q(n2T_z) \\ P_l(n2T_Z + T_S) & Q_l(n2T_z + T_S) \\ . & \\ . & \\ P_l(n2T_z + (N-1)T_S) & Q(n2T_z + (N-1)T_S) \end{bmatrix} \begin{bmatrix} D_0 \\ D_1 \end{bmatrix} \tag{5}$$

or
$$\boldsymbol{S}_{Z_{n,l}} = \boldsymbol{B}_{Z_{n,l}} \bullet \boldsymbol{Y}_n^{\,2} \tag{6}$$

where $\boldsymbol{Y}_n^{2} = [D_0 \quad D_1]^T$, n is any positive integer

$$P(t) = \cos\left(\frac{\pi t}{2T_Z}\right) \cos 2\pi f_h t \tag{7}$$

$$Q(t) = \sin\left(\frac{\pi t}{2T_Z}\right) \sin 2\pi f_h t \tag{8}$$

Where subscript l denotes the l^{th} Zigbee channel and subscript n is given to denote n^{th} time instant. Matrix $\boldsymbol{B}_{Z_{n,l}}$ is an $N \times 2$ matrix consisting of 2 columns of $P_l\ (t),\ Q_l\ (t)$ multiplied by the square root of the power P. In equation (6) the superscript "2" denotes that matrix, $\boldsymbol{Y}_n^{\,2}$ is generated from 2 unknown binary data. Similarly for p (where p is even) unknown binary data can be written as:

$$\boldsymbol{S}_{Z_{n,l}}^{p} = \boldsymbol{B}_{Z_{n,l}}^{p} \bullet \boldsymbol{Y}_n^{\,p} \tag{9}$$

Where $\boldsymbol{S}_{Z_{n,l}}^{p}$, $\boldsymbol{B}_{Z_{n,l}}^{p}$, $\boldsymbol{Y}_n^{\,p}$ is of dimension $N_1 \times 1$, $N_1 \times p$, $p \times 1$ respectively. The superscript "p" denotes the number of binary Zigbee data transmitted during one the OFDM symbol period and $\boldsymbol{Y}_n^{p} = \left[D_0 \;\; D_1 \;\; D_2 \ldots.\;\; D_{p-1}\right]^T$ where $D_0, D_1 \ldots D_{p-1}$ are binary data transmitted by Zigbee system. So vector of Zigbee samples $\boldsymbol{S}_{Z_{n,l}}^{p}$ depend on the particular combination binary data vector $\boldsymbol{x}_j = \{D_0 D_1 D_2 \ldots. D_{p-1}\}$. Therefore, to denote the dependency on a particular combination of data input vector the equation(9) is written as:

$$\boldsymbol{S}_{Z_{n,l,j}}^{p} = \boldsymbol{B}_{Z_{n,l}}^{p} \bullet \boldsymbol{Y}_{n,j}^{p} \tag{10}$$

The received Zigbee data vector $\boldsymbol{S}_{Z_{n,l}}^{p}$ in OFDM receiver is passed through a low pass filter of impulse response $h_{lpf}(t)$. Let $\boldsymbol{T}_s^{OFDM}$ and T_s^{Zigbee} be the sampling time of the OFDM and BT signal respectively. Then the filtered Zigbee samples in OFDM system will be[3]:

$$i(n) = \sum_{m=0}^{N_1-1} h_{lpf}\left(nT_s^{OFDM} - mT_s^{Zigbee}\right) \boldsymbol{S}_{Z_{n,l,j}}^{p}(m) \tag{11}$$

After passing through the cyclic prefix removal block the above equation can be written in matrix form as:

$$\boldsymbol{i}^{N_{FFT}} = \boldsymbol{R}_{cp} \bullet \boldsymbol{h}_{lpf} \bullet \boldsymbol{S}_{Z_{n,l,j}}^{p} = \boldsymbol{h}_1 \bullet \boldsymbol{B}_{n,l}^{p} \bullet \boldsymbol{Y}_{n,j}^{p} \tag{12}$$

$\boldsymbol{R}_{cp}$ is cyclic prefix removal matrix of dimension $N_{FFT} \times (Ncp + N_{FFT})$, Ncp is the length of cyclic prefix. $\boldsymbol{h}_{lpf}$ is generated from tap value of receiver low pass filter.

$\boldsymbol{i}^{N_{FFT}} = \left[i_0 \;\; i_1 \;.. \;\; i_{N_{FFT}-1}\right]^T$, $\boldsymbol{h}_1 = \boldsymbol{R}_{cp} \bullet \boldsymbol{h}_{lpf}$,

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After FFT operation in the OFDM receiver the vector consist of interference component for the OFDM sub carriers is given by :

$$\boldsymbol{I_j = F \bullet h_1 \bullet B^p_{Z_{n,l}} \bullet Y^p_{n,j}} \tag{13}$$

Where $\boldsymbol{F}$ is 64×64 FFT matrix. And $\boldsymbol{I} = [I_{0,j}, I_{1,j}, I_{2,j} \ldots I_{k,j} \ldots I_{63,j}]^T$.

Let I_k denotes the interference corresponding to the k[th] subcarrier and $\boldsymbol{F_k}$ denotes the k^{th} row of the FFT matrix $\boldsymbol{F}$, then I_k is expressed as:

$$I_{k,j} = \boldsymbol{F_k \bullet h_1 \bullet B^p_{Z_{n,l}} \bullet Y^p_{n,j}} \tag{14}$$

According IEEE802.11g standard [4] one OFDM symbol period $T_{OFDM}=4\mu s$ and one Zigbee[5] symbol period $T_Z=.5\mu s$. As Zigbee is using O-QPSK data per *cos or sin* pulse will remain unchanged for $2T_Z=1\mu s$. So it can be found for 4us of OFDM signal there will be 16 unknown data for Zigbee (combining both sin and *cos* pulse's data), basically which implies 9 combination of unknowns. As OFDM will remove the cyclic prefix length which is one fourth of the symbol duration, that is 0.8 µs, so for the rest 3.2 µs there will 8 unknown Zigbee data. Now $\boldsymbol{Y^p_{n,j}}$ is a 8×1 matrix consist of 8 unknown binary data and matrix $\boldsymbol{B^p_{Z_{n,l}}}$ is of $N_1\times 8$.Let

$$\boldsymbol{B^p_{Z_{n,l}} = [C1\ C2\ C3\ \ C4\ C5\ C6\ C7\ C8]} \tag{15}$$

So the eq(14) can be rewritten as:

$$I_{k,l,j} = \sum_{n=0}^{7} a_n D_n \tag{16}$$

Then $a_0 = \boldsymbol{F_k \bullet h_1 \bullet C1}$; $a_1 = \boldsymbol{F_k \bullet h_1 \bullet C2}$;
$a_2 = \boldsymbol{F_k \bullet h_1 \bullet C3}$; $a_3 = \boldsymbol{F_k \bullet h_1 \bullet C4}$; $a_4 = \boldsymbol{F_k \bullet h_1 \bullet C5}$;
$a_5 = \boldsymbol{F_k \bullet h_1 \bullet C6}$; $a_6 = \boldsymbol{F_k \bullet h_1 \bullet C7}$; $a_7 = \boldsymbol{F_k \bullet h_1 \bullet C8}$

B. Interference frequency estimation

Let Δf be the sub carrier spacing of the OFDM sub carriers and k[th] sub carrier have maximum energy. If the OFDM frequency band ranges from f_{start} to f_{finish} then Zigbee's frequency is given by

$$f_h = round\left(f_{start} + \left(\Delta f \times k\right)\right) \tag{17}$$

Where, f_{finish}- f_{start} = BMHz , B is the estimation band of WLAN.

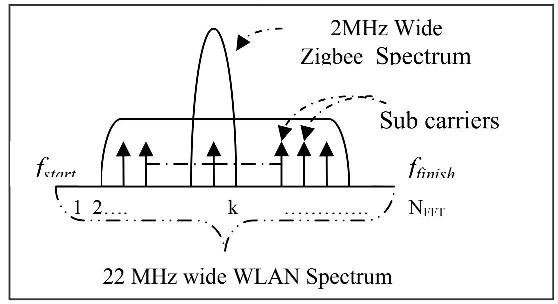

Figure 2: Zigbee inside WLAN frequency band

C. Channel estimation and Interference power estimation:

Training signal are used to estimate both channel taps and the instantaneous power of the interference signal. Let $\boldsymbol{u_{Train}}$ is the set of training signal after IFFT in the transmitter of an OFDM system.

$$\boldsymbol{u_{Train}} = \boldsymbol{F^H} \bullet \boldsymbol{U_{Train}} = \left[u_0\ u_1\ \ldots\ u_{N_{FFT}-1}\right] \tag{18}$$

If $u1_{Train}$ is the received matrix at the receiver before FFT operation then it is given by:

$$\boldsymbol{u1_{Train}} = \boldsymbol{R_{cp} \bullet H_0 \bullet T_{cp} \bullet u_{Train}} \tag{19}$$

$$= \boldsymbol{\tilde{H} \bullet u_{Train}} \tag{20}$$

where $\boldsymbol{\tilde{H}}$ is $N_{FFT}\times N_{FFT}$ circulant matrix which is given below:

$$\boldsymbol{\tilde{H}} = \begin{bmatrix} h_0 & 0 & \cdots & 0 & h_{L-1} & \cdots & h_2 & h_1 \\ h_1 & h_0 & 0 & \cdots & 0 & h_{L-1} & \cdots & h_3\ h_2 \\ \vdots & & & & & & & \vdots \\ h_{L-2} & h_{L-3} & \cdots h_1 & h_0 & 0 & \cdots & 0 & h_{L-1} \\ h_{L-1} & \cdots & h_1 & h_0 & 0 & \cdots 0 & \cdots & 0 \\ 0 & h_{L-1} & \cdots & h_1 & h_0 & 0 & \cdots & 0 \\ \vdots & & \vdots & & & & & \\ \vdots & & \vdots & & & & & \\ 0 & \cdots & & 0 & h_{L-1} & \cdots & h_1 & h_0 \end{bmatrix} \tag{21}$$

Now equation (20) is rewritten as:

$$\boldsymbol{u1_{Train}} = \boldsymbol{\tilde{u}_{Train} \bullet h} \tag{22}$$

Where

$$\boldsymbol{\tilde{u}_{Train}} = \begin{bmatrix} u_0 & u_{N_{FFT}-1} \ldots u_{N_{FFT}-(L-1)} \\ u_1 & u_0 \ldots\ldots u_{N_{FFT}-(L-2)} \\ \vdots & \vdots \quad \vdots \\ \vdots & \vdots \quad \vdots \\ u_{N_{FFT}-1} & u_{N_{FFT}-2} \quad u_{N_{FFT}-L} \end{bmatrix} \tag{23}$$

and $\boldsymbol{h} = (h_{L-1} \ldots\ldots h_1\ h_0)^T$ and $\boldsymbol{\tilde{u}_{Train}}$ is a matrix of dimension $N_{FFT}\times L$ consisting training signals.

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Replacing $h_1 \bullet B^p_{Z_{n,l}} = h_2$ in equation(12), the Zigbee interference in OFDM receiver before IFFT can be written as:

$$i^{N_{FFT}} = h_2 \bullet Y^p_{n,j} \tag{24}$$

Now in presence of AWGN noise and Zigbee interference the received signal before FFT operation is written in matrix form as:

$$\hat{u}1_{Train} = u1_{Train} + i^{N_{FFT}} + n1 \tag{25}$$

Where **n1** is AWGN noise

$$\hat{u}1_{Train} = \left(\tilde{u}_{Train} \bullet h\right) + \left(h_2 \bullet Y^p_{n,j}\right) + n1 \tag{26}$$

$$= \left[\tilde{u}_{Train} \quad h_2\right]\begin{bmatrix} \mathbf{h} \\ Y^p_{n,j} \end{bmatrix} + n1 \tag{27}$$

$$= Ay + n1 \tag{28}$$

where $A = \left[\tilde{u}_{Train} \quad h_2\right]$ is of dimension $N_{FFT}\times(L+2p)$. and $y = \left(h^T \; Y^p_{n,j}\right)^T$ is matrix of dimension $(L+2p)\times 1$ consist of unknown channel vector and unknown Zigbee signal vector. From eq(29) unknown parameters of matrix y can be estimated near to the actual value if noise is negligible by the equation given below:

$$y = A^{-1}\hat{u}1_{Train} - A^{-1}n1 \tag{29}$$

Let be the vector of estimated vector Zigbee signal from then estimated Zigbee samples corresponding to the p symbol will be:

$$\hat{S}^p_{Z_{n,l,j}} = B^p_{Z_{n,l}} \bullet \hat{Y}^p_{n,j} \tag{30}$$

B. Interference Cancellation Algorithm

The received signal for the null sub carriers of the OFDM receiver is given by[5]:

$$R_k = I_k + N_k \tag{32}$$

It can be shown I_k can be expressed as function of transmitted binary input signal of the Zigbee system as:

$$I_k = V_k \bullet x_j \tag{33}$$

Where x is matrix of unknown transmitted binary inputs corresponds one OFDM symbol period and

$$x \in \{-1-1-1-1-1-1-1-1, \ldots\ldots, 11111111\} = \{x_0, x_1, \ldots\ldots x_{255}\}$$

and V_k is matrix generated depending upon modulation , pulse shaping of the Zigbee system and equivalent low pass filter ,FFT matrix of the OFDM receiver and V_k can be expressed as:

$$V_k = F_k \bullet h_1 \bullet B^8_{Z_{n,l}} \tag{34}$$

And $$x_j = Y^8_{n,j} \tag{35}$$

Where F_k is subset of FFT matrix corresponds to the chosen set of $p=8$ null carriers and is of cdimension $1\times N_{FFT}$,. h_1 is generated from low pass filter response of OFDM receiver, $B^8_{Z_{n,l}}$ is generated from transmitted frequency, modulation ,pulse shaping characteristics of Zigbee system. Assuming hopping frequency, power of the interference signal has been measured perfectly using OFDM training signals], estimation of interference in OFDM data signals is done as follows:

1. For each data input vector x_j, where $j \in \{0,1,\ldots,255\}$, generate V_k and find the interference for each of the set of p null sub-carrier using the equation below:

$$V_k x_j = F_k \bullet h_1 \bullet B^8_{Z_{n,l}} \bullet x_j = I_{k,j}\,. \tag{36}$$

2. Take the Difference $E_{k,j} = Y_k - I_{k,j}$ and obtain the magnitude of $\left|E_{k,j}\right|$. Average $\left|E_{k,j}\right|$ over all the chosen set of null sub-carriers using the equation below:

$$E_j = \frac{1}{p}\sum_{k=0}^{p-1}\left|E_{k,j}\right| \tag{37}$$

3. Choose x_j that will minimize the average error E_j

4. For the above chosen x_j obtain the interference component for all the sub-carriers of one OFDM signal.

5. Subtract the above obtained estimated Zigbee interference for each sub-carrier from the received signal. Repeat the above procedure from step 1 to 5 for the next OFDM signal to cancel out Zigbee interference.

IV. Simulation Results

In all simulation results SIR is ratio of total OFDM power of all sub-carriers with interferer (BT) power. SNR is the ratio of total OFDM power with additive white Gaussian noise. In figure 6 technique1 refers to the narrowband cancellation method[3] where estimation of transmitted data of narrowband interference and reconstruction of its waveform is done by measuring interference information on certain unmodulated null sub-carriers and using erasures[1] refers to the techniques of replacing nulls in the sub-carriers where the narrowband interference signal has hopped in OFDM frequency range.

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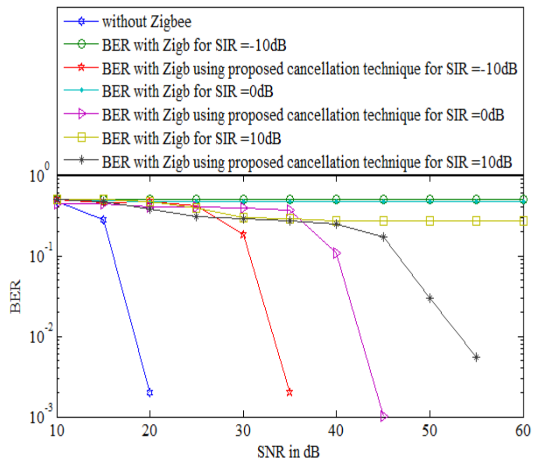

Figure 3: Comparison of coded BER for 64QAM OFDM based WLAN with and without Zigbee in AWGN

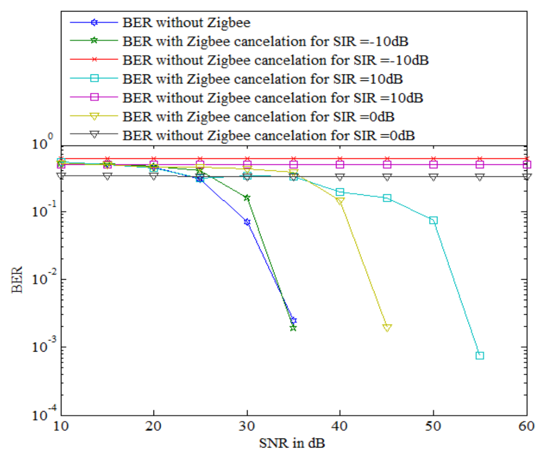

Figure 4. Comparison of Coded BER for 64QAM OFDM based WLANs in presence of Zigbee interference in flat Rayleigh fading channel using proposed cancellation algorithm

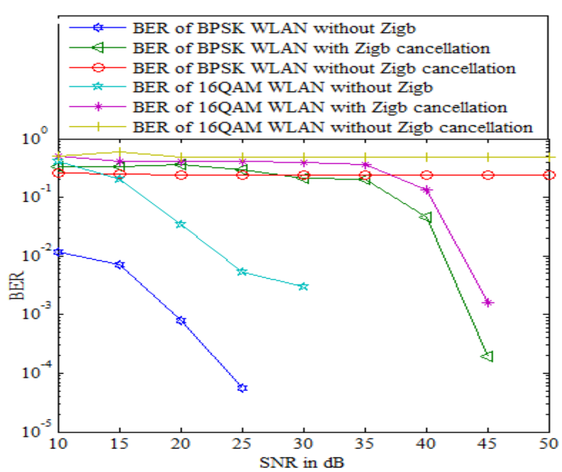

Figure 5. Comparison of Coded BER for 16QAM OFDM, BPSK-OFDM based WLANs in presence of Zigbee interference in flat Rayleigh fading channel using proposed cancellation algorithm

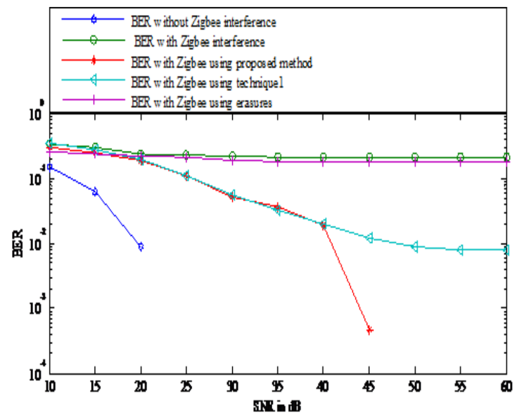

Figure6. Comparison of uncoded BER of 64QAMWLAN with different techniques in AWGN for scenario in figure2. Technique1 is the technique used in ref[3].

V. SUMMARY

This paper proposes an algorithm for extracting out Zigbee interference component present in all OFDM subcarriers and cancelling those estimated Zigbee signal's part from received signal in OFDM receiver. Simulation result shows algorithm.

gives significant improvement in performance particularly when SNR value is high, almost zero BER can be obtained in presence of Zigbee interference for OFDM based WLANs. As initial estimation of amplitude or frequency cannot be obtained accurately for low SNR values performance in terms of BER will not improve much using proposed algorithm for low SNR. So applying this algorithm will nullify the Zigbee interference present in all OFDM based WLAN subcarriers and give one a step solution towards coexistence of WLAN and Zigbee system

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